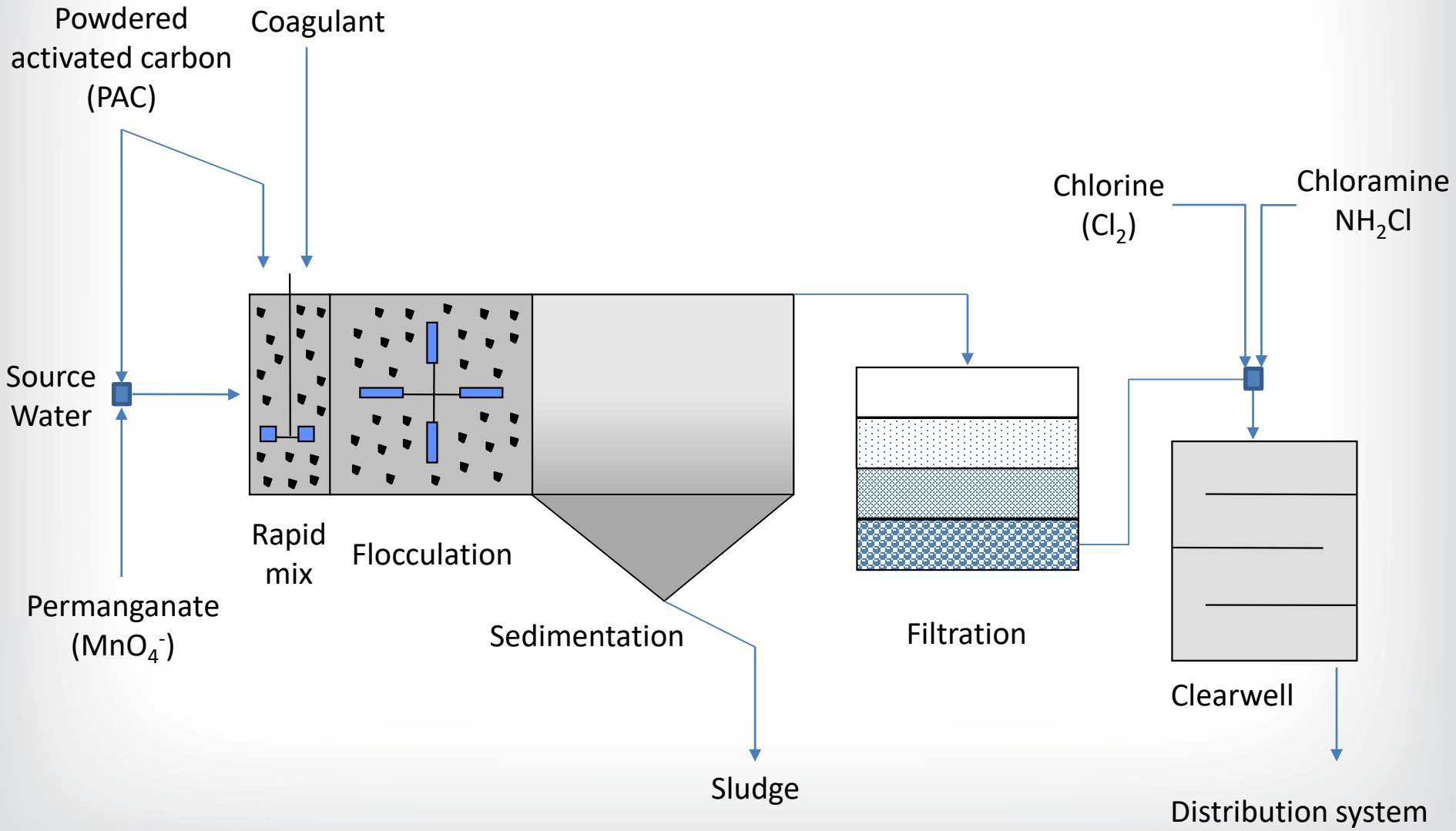
U.S. Environmental Projection Agency, Office of Research and Development

SAFE AND SUSTAINABLE WATER RESOURCES RESEARCH PROGRAM

Conventional Treatment Options For HABs Impacted Waters

Nicholas Dugan, PE
Thomas Waters, PE

Conventional surface water treatment process



Definitions

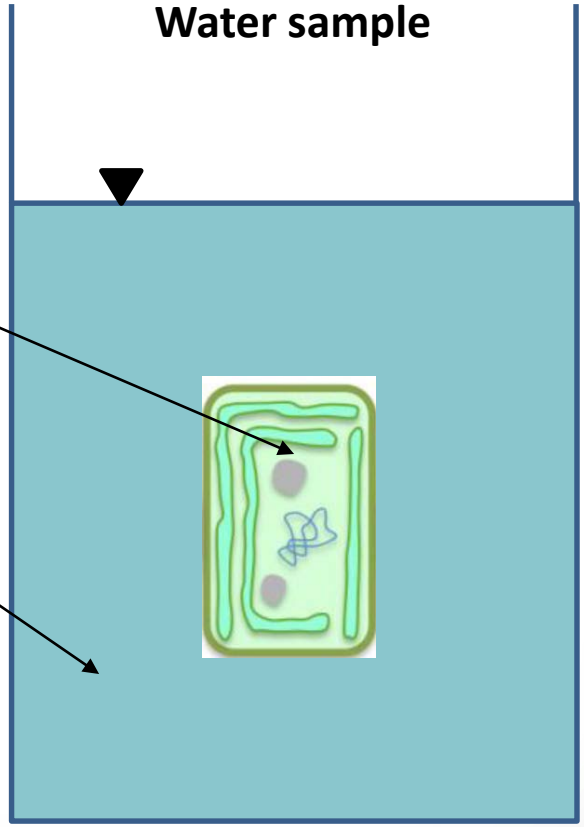
- Cell counts: direct counting of cells under a microscope
- Chlorophyll: pigment molecules in algae and cyanobacteria that play a role in photosynthesis
- Phycocyanin: pigment molecules in cyanobacteria that play a role in photosynthesis
- Microcystin: A type of toxin produced by cyanobacteria, most commonly detected, affects the liver

Combined, intracellular and extracellular toxins

Intracellular
Toxins contained inside the cell

Extracellular
Toxins in solution outside the cell

Combined
Extracellular + intracellular toxin



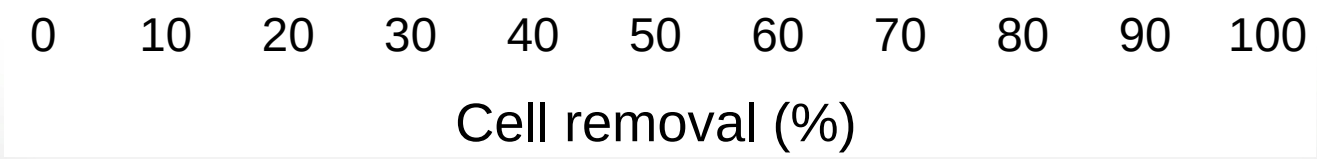
Jar testing

Removals through coagulation and sedimentation

Full-scale, 150-220 mg/L
Polyaluminum chloride[1]

Pilot-scale, 70 mg/L alum[2]

Jar test, 65 mg/L alum[2]



[1]Zamyadi et al; *Species Dependence of Cyanobacteria Removal Efficiency by Different Drinking Water Treatment Processes*; Water Research; 2013:47:2689-2700
[2]Drikas et al; *Using Coagulation, Flocculation and Settling to Remove Toxic Cyanobacteria*; Journal AWWA; 2001:93:2:100-111

Toxin removals through pilot-scale coagulation, sedimentation and filtration

Sample point	Toxin type	Microcystin-LR concentration (µg/L) Trial 1	Trial 2
Influent	Combined	119	60
	Extracellular	3	2
Effluent	Combined	3	2
	Extracellular	3	2

Source: Drikas et al; *Using Coagulation, Flocculation and Settling to Remove Toxic Cyanobacteria*; Journal AWWA; 2001:93:2:100-111

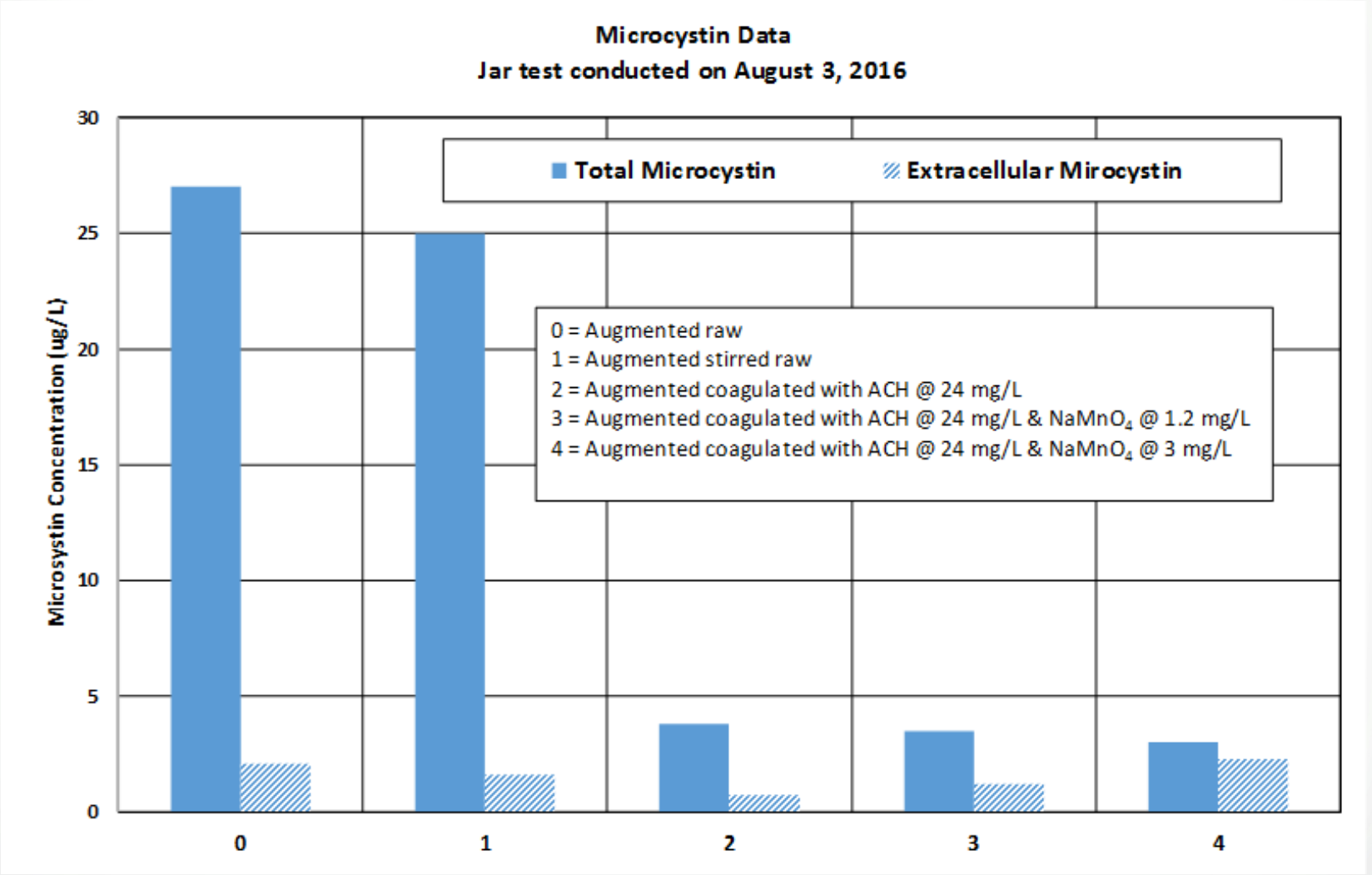
Bench-scale coagulation experiments with *M. aeruginosa*

Water source/pH	Dose necessary to achieve 80% removal of cells (mg/L)		
	Aluminum chlorohydrate	Ferric chloride	Aluminum sulfate
Myponga Reservoir			
pH 7.5 – 7.8	40	40	60
pH 6.3	20	40	60
River Murray			
pH 7.2 – 7.6	20	40	80
pH 6.3	20	20	60

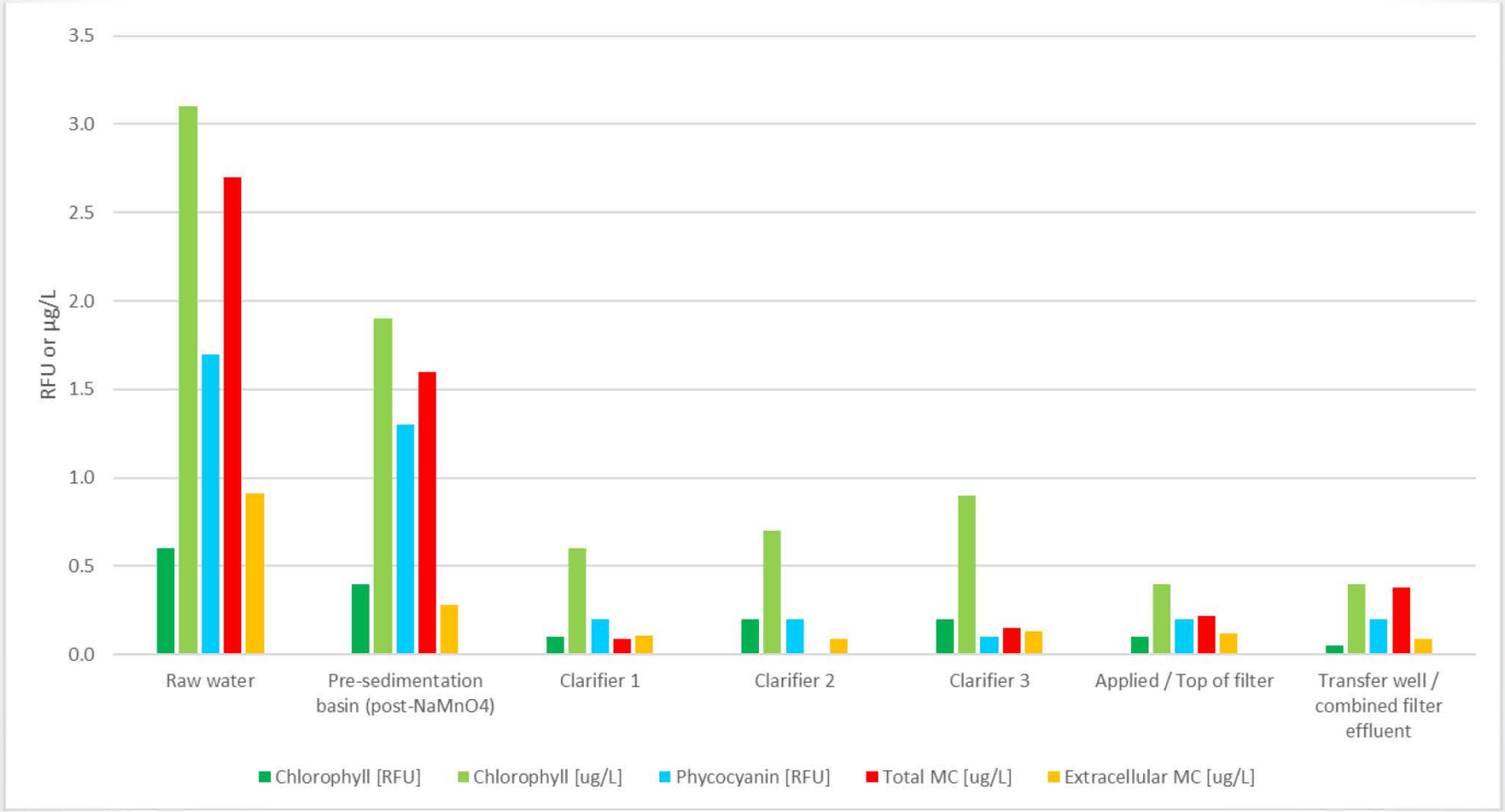
Myponga turbidity = 1.2 – 8.7 NTU, DOC = 10 – 12 mg/L
Murray turbidity = 23 – 101 NTU, DOC = 5.3 - 17

Source: Newcombe, G. et al; *Optimizing Conventional Treatment for the Removal of Cyanobacteria and Toxins*; Water Research Foundation, Denver CO; 2015

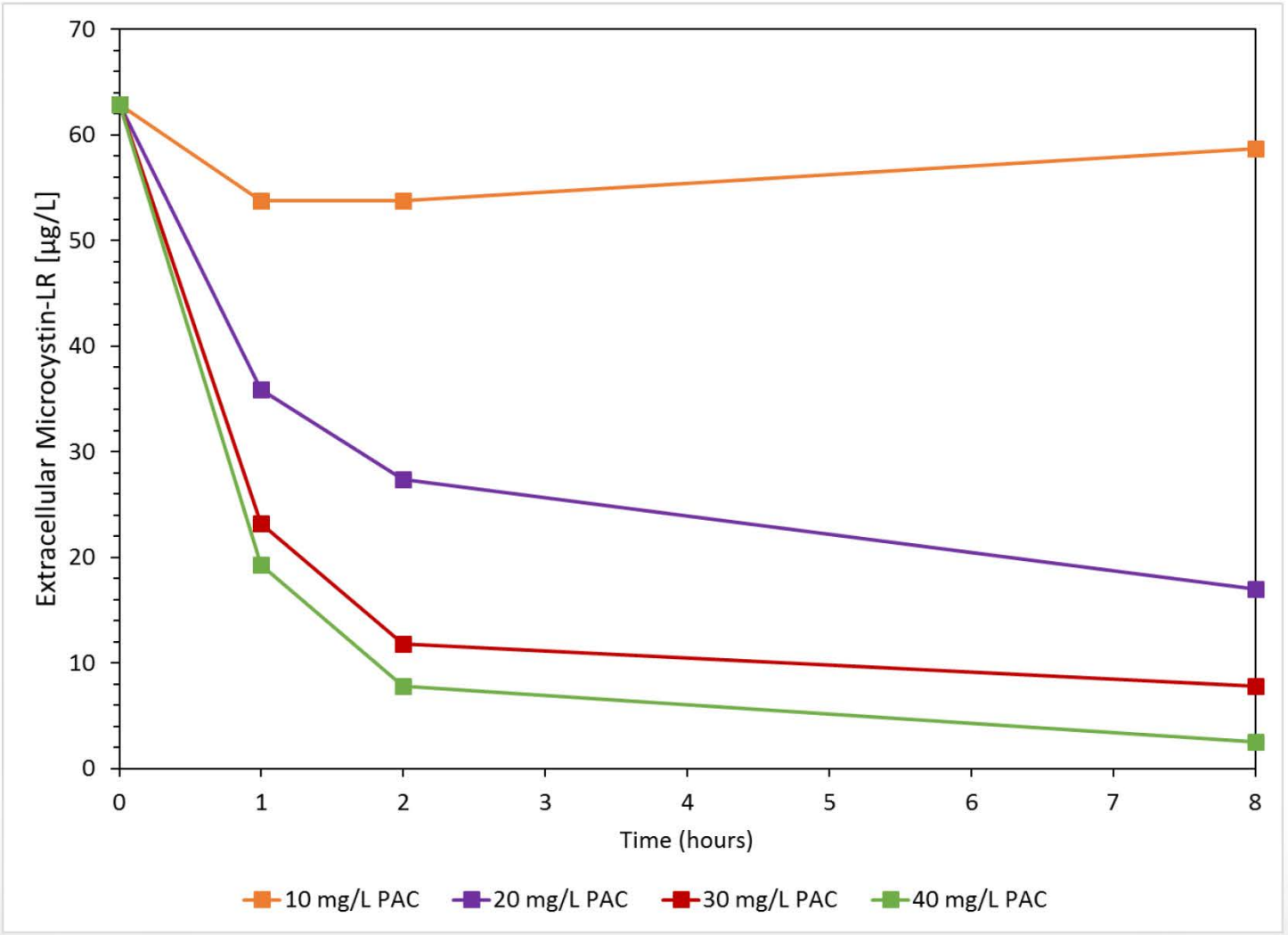
Bench-scale coagulation experiments with Lake Erie water and cyanobacteria



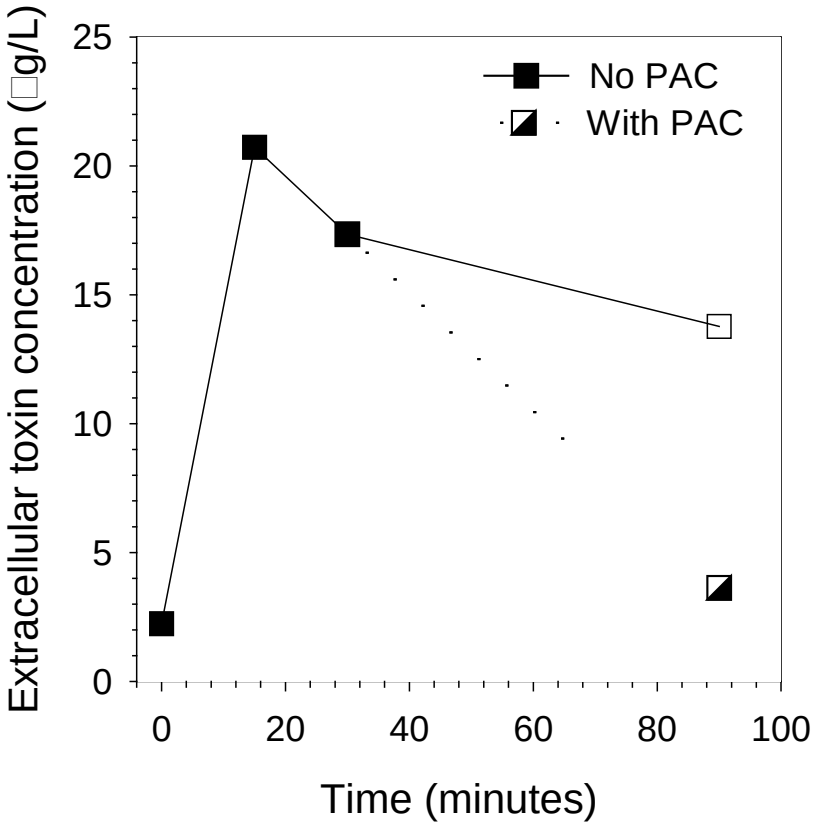
Through-plant sampling – Lake Erie water treatment plant

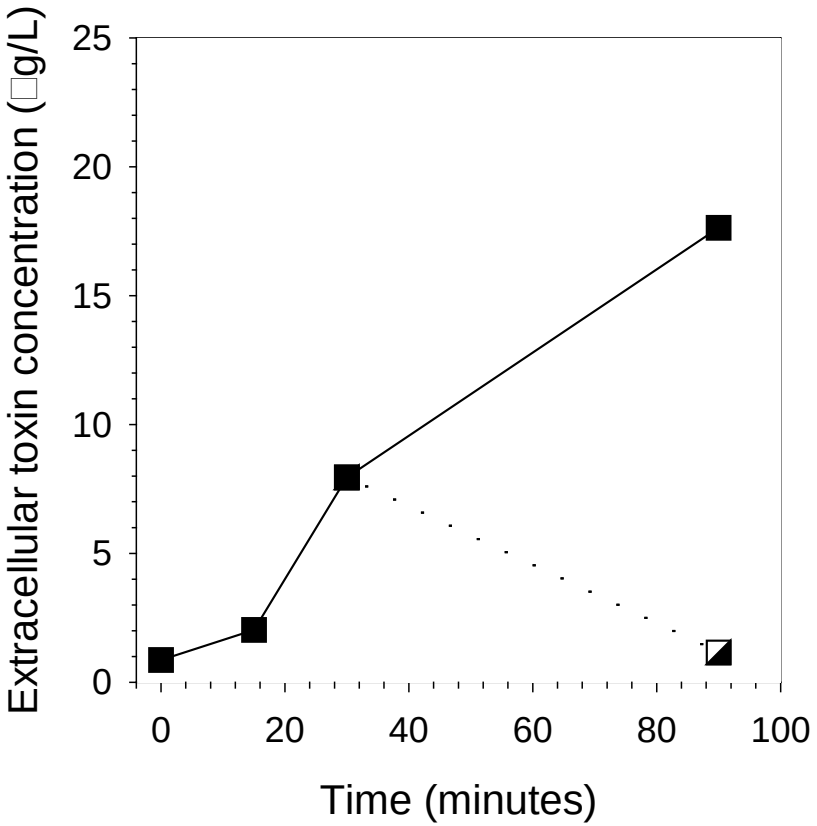


Impact of powdered activated carbon (PAC) addition – microcystin spiked into raw surface water

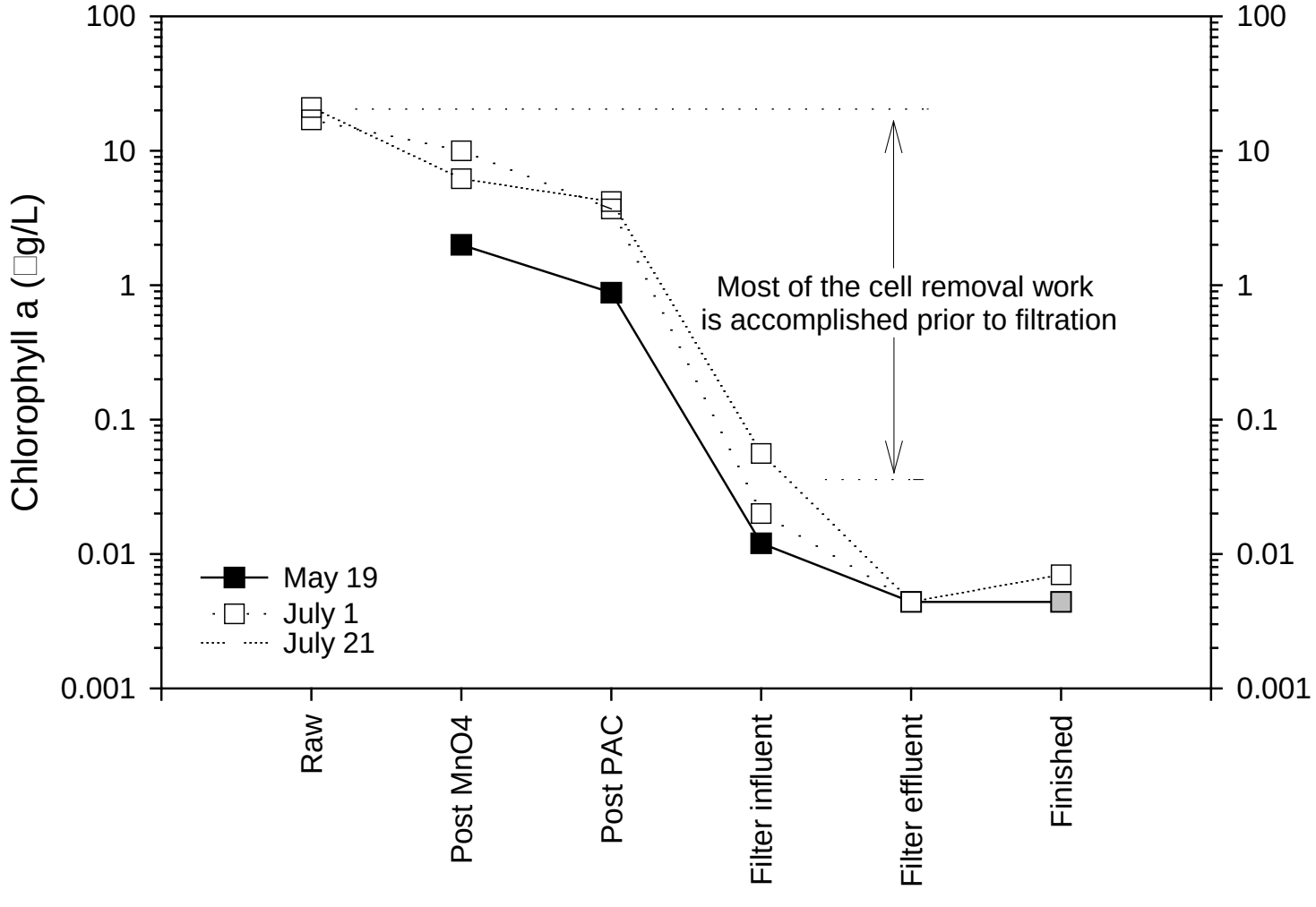


Impact of powdered activated carbon (PAC) addition – carbon added after toxin release from cyanobacterial cells

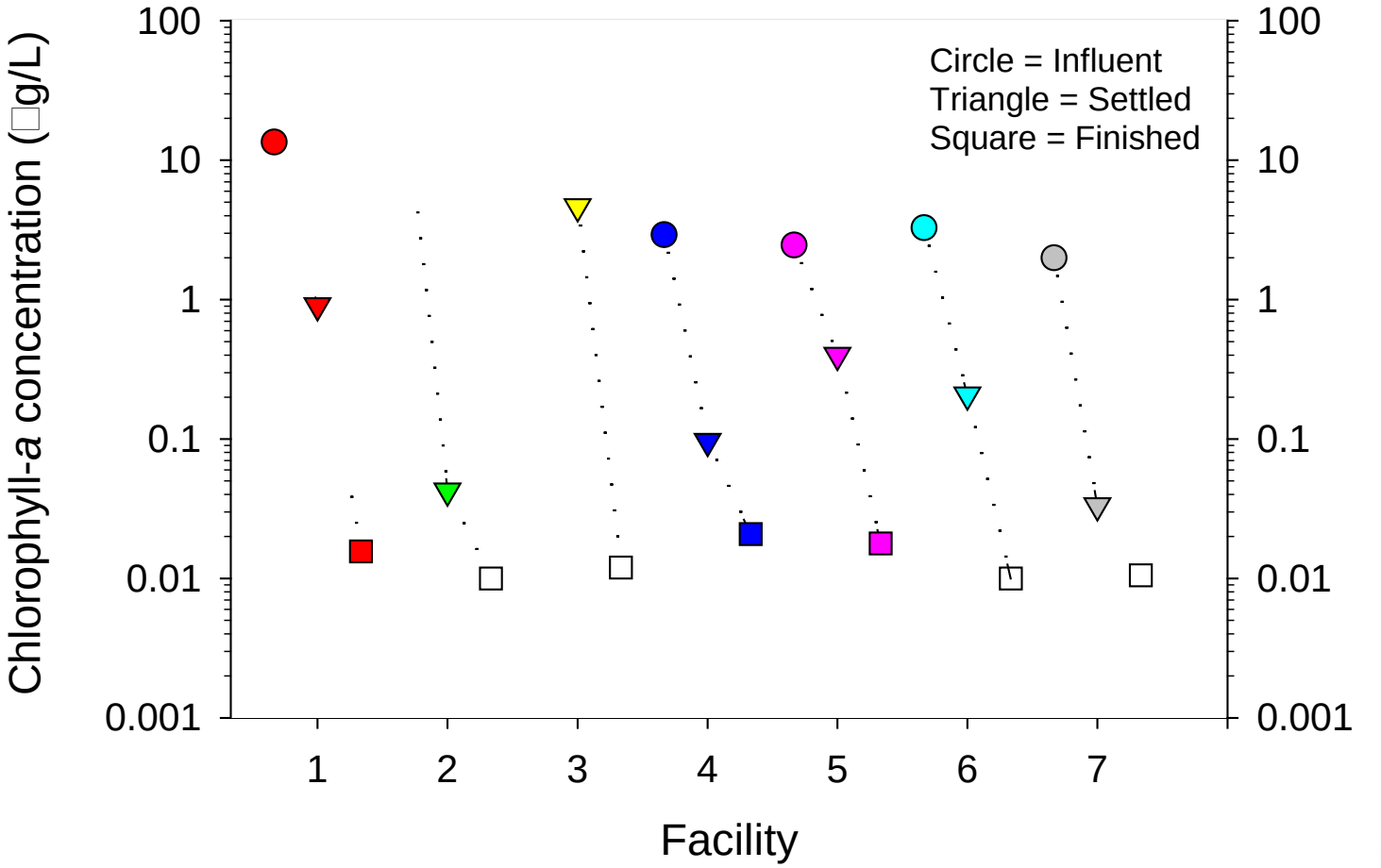




Cell propagation through a full-scale Lake Erie treatment facility



Physical removal of cells through seven full-scale Lake Erie facilities



Each data point represents the average of 5 – 7 samples collected between May and October

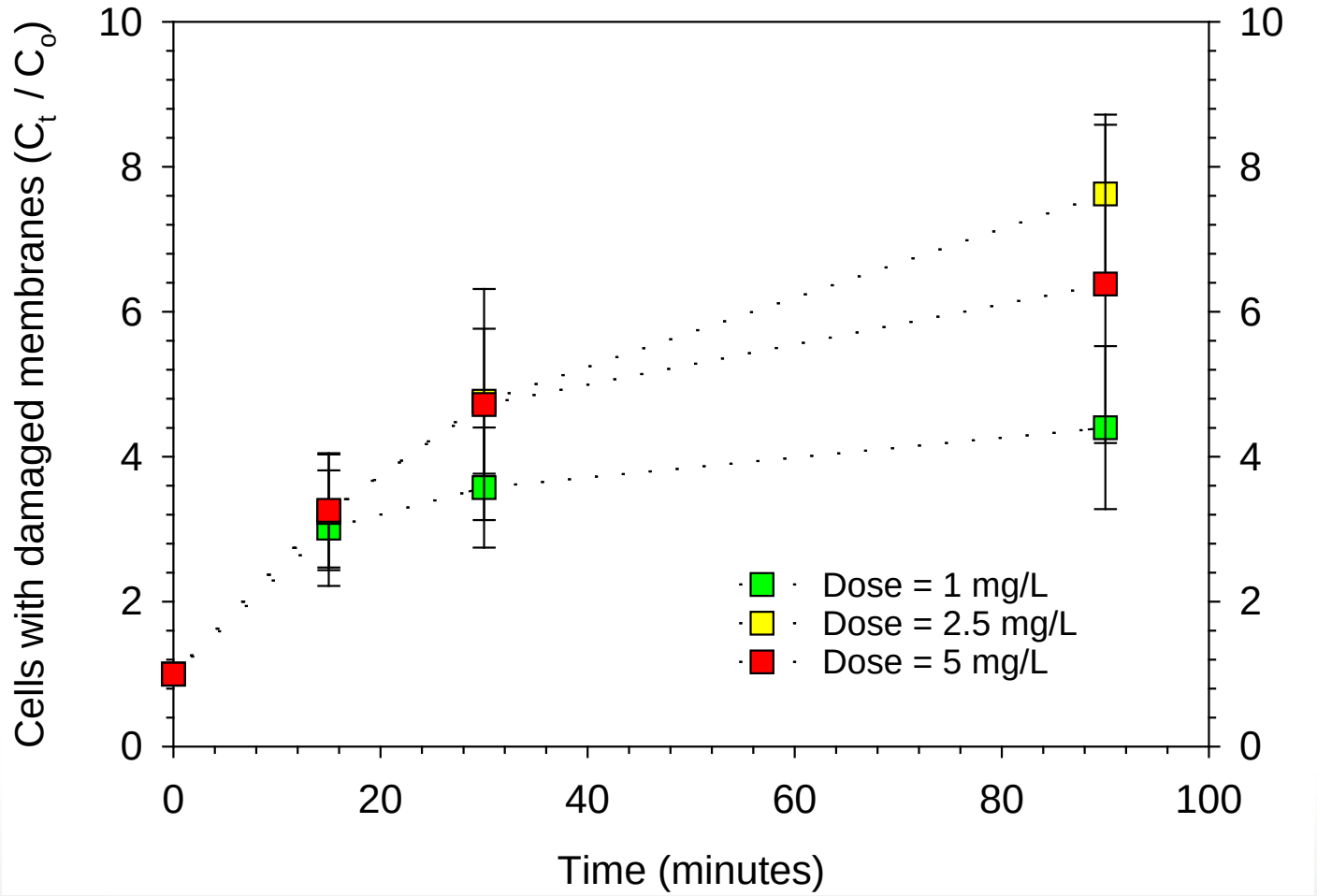
West → 150 miles → East

Filtration of *M. aeruginosa* Pilot-scale seeding trial results

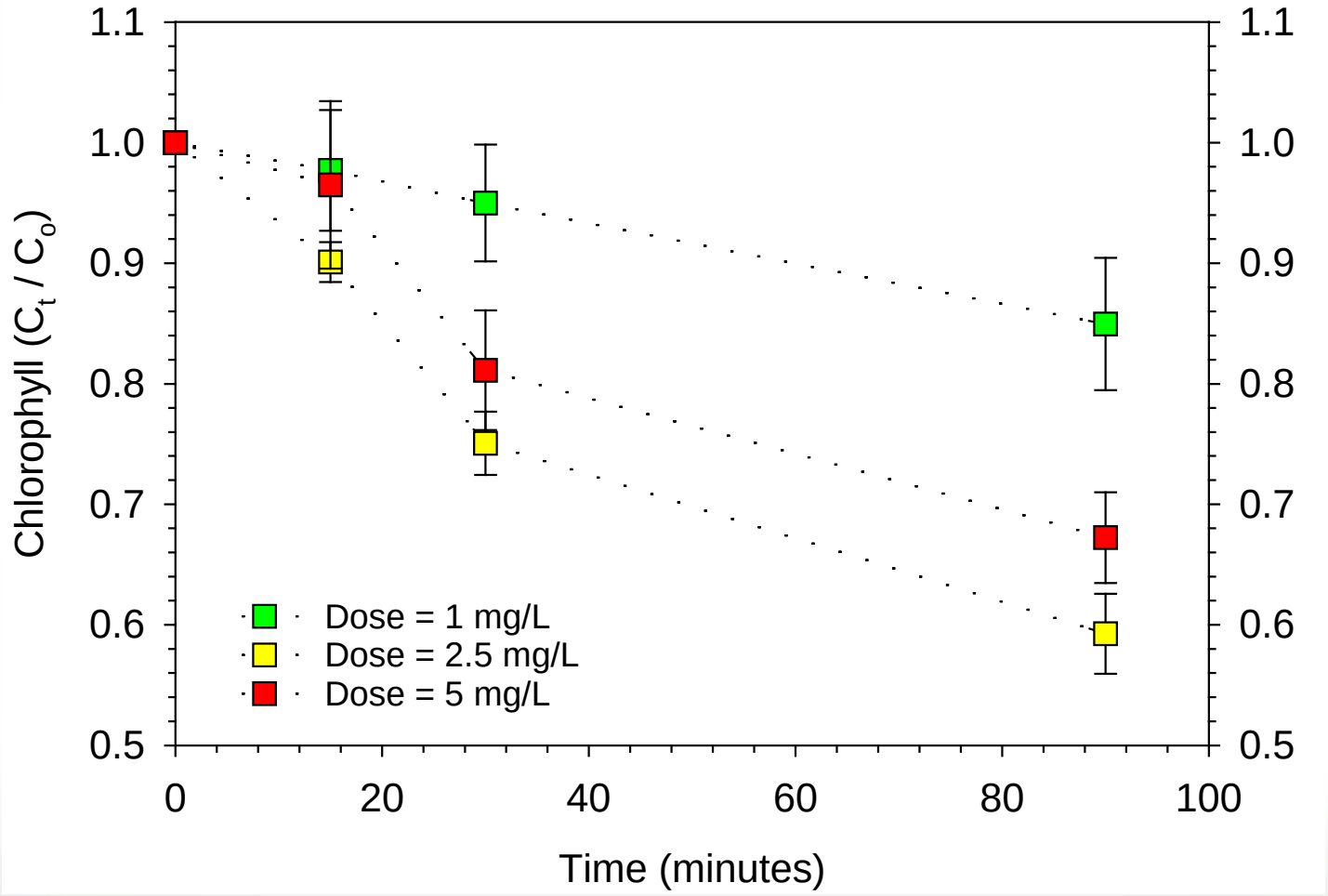
Coagulant	Baseline filter loading rate (m/hr)	Steady-state removal of chlorophyll-*a* (Δ log)
Alum + cationic polymer	7	2.8
	10	2.5
Ferric chloride + cationic polymer	7	2.9
	10	3.8

- Average influent chlorophyll-*a* concentration = 26 µg/L (SD = 12 µg/L)
- 1 m/hr = 0.41 gal/min•ft^2

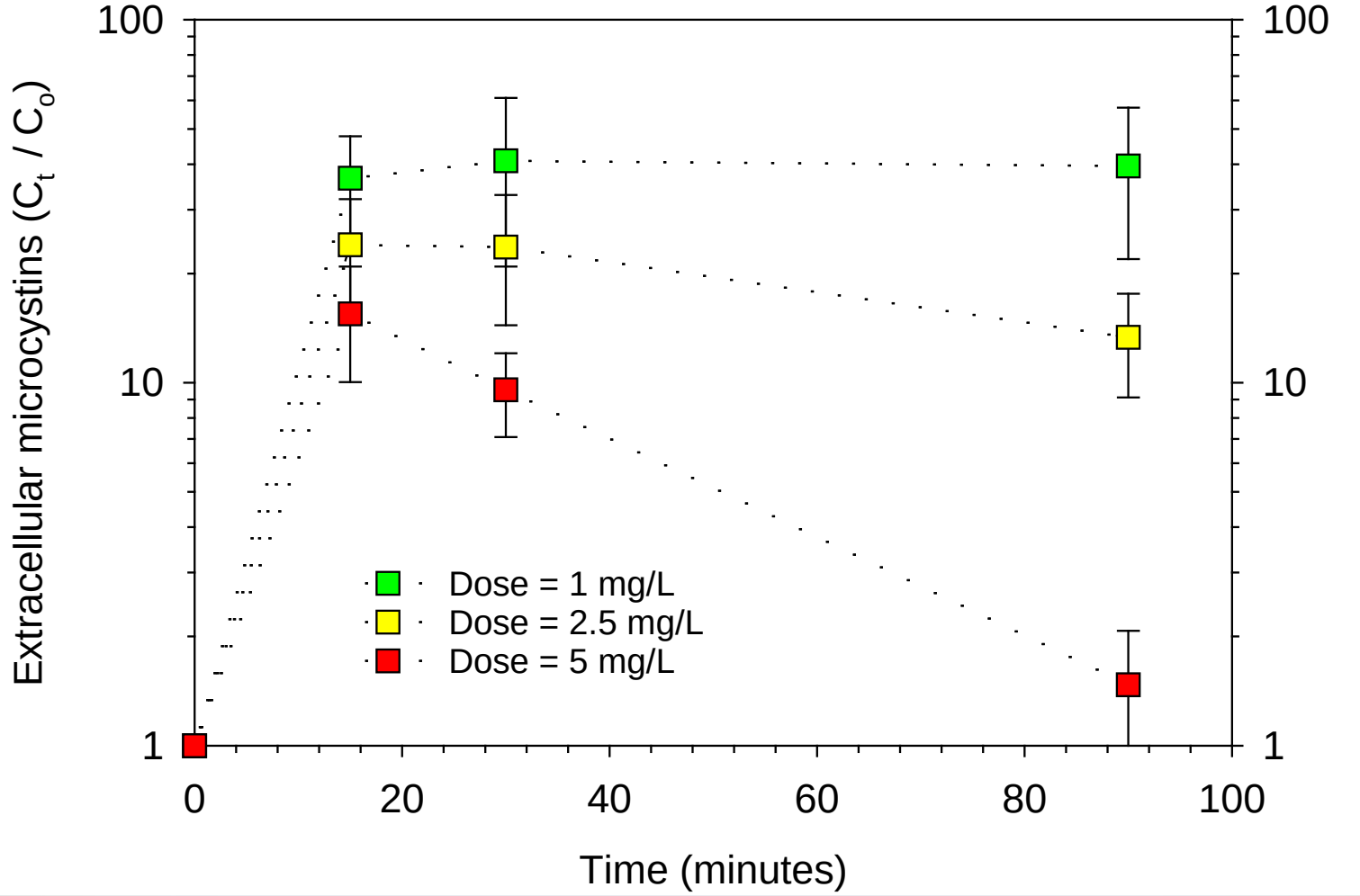
Impact of $KMnO_4$ on cyanobacterial cell membrane integrity



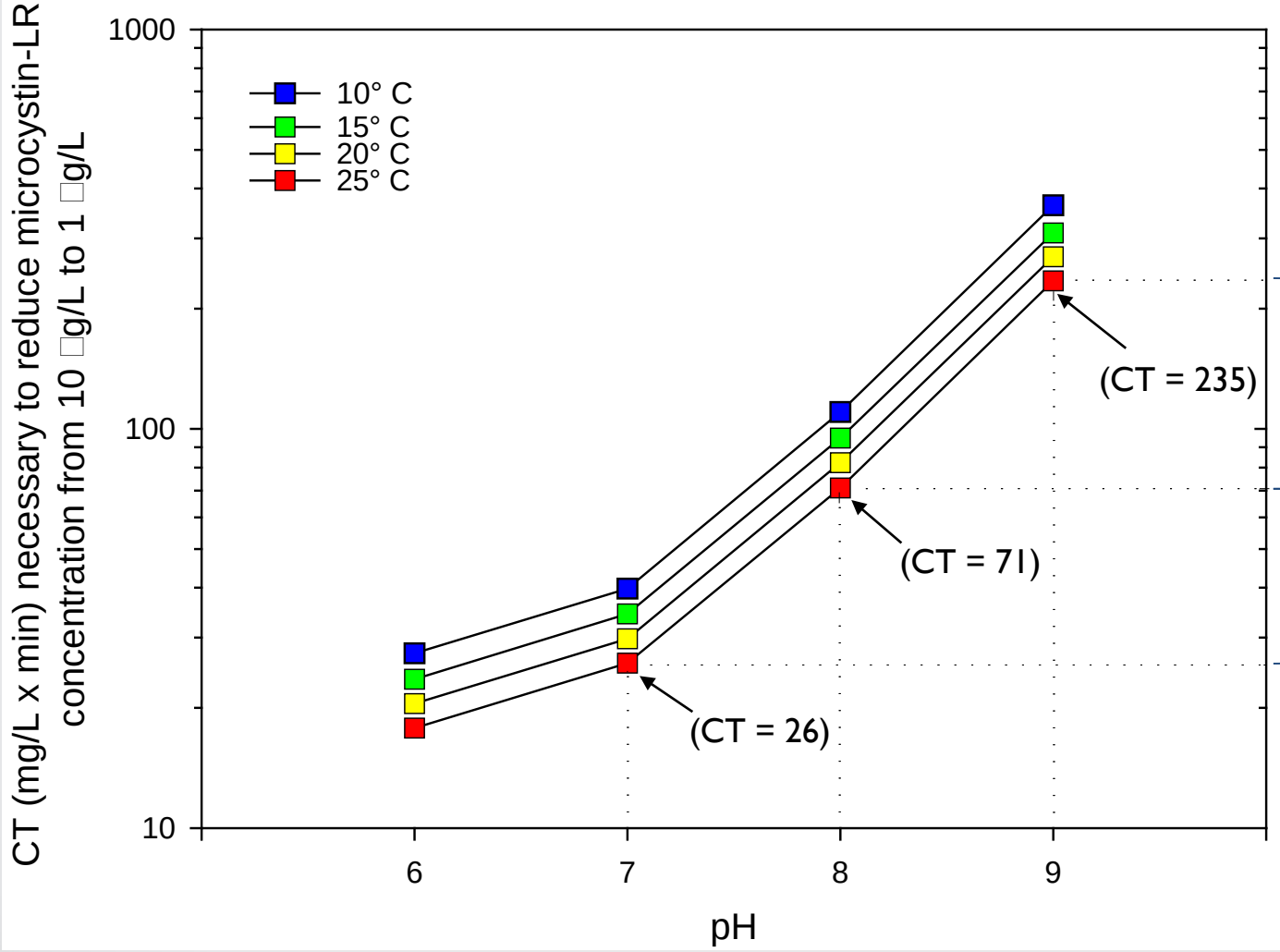
Impact of $KMnO_4$ on chlorophyll in cyanobacterial cells



Impact of $KMnO_4$ on toxin release from cyanobacterial cells and subsequent degradation



Impact of chlorination on microcystin concentrations



CT for 3-log *Giardia* inactivation @ 1.0 mg/L Cl_2, t = 25° C:

- pH 7: 37
- pH 8: 54
- pH 9: 78

> 3X increase in CT

> 2X increase in CT

*Figure based on data from Acero et al, *Water Research*, 2005:39:1628-1638

UV irradiation

- UV contactors installed toward the end of the treatment process – cells and intracellular toxins have been removed, only extracellular toxin remaining
- Required UV doses for 2-log disinfection of *Cryptosporidium* = 5.8 mJ/cm^2, *Giardia* = 5.2 mJ/cm^2, virus = 100 mJ/cm^2
- These doses drive full-scale UV contactor design
- UV doses required for microcystin degradation are significantly higher – existing UV infrastructure not a barrier to toxin passage

Ozone and chlorine dioxide

- Chlorine dioxide, at the doses used in drinking water treatment (to limit the formation of chlorite) is not considered effective against microcystins – reaction rate is approximately 3 orders of magnitude lower than permanganate
- Ozone has been proven effective at degrading microcystins as well as cylindrospermopsins and anatoxin – reaction rate is sufficient to achieve degradation within the confines of ozone contactors used in full-scale drinking water treatment

Conclusions

- Core conventional treatment processes – coagulation, flocculation, sedimentation, filtration - are highly effective at removing cyanobacterial cells – shown to work across a range of coagulants
- PAC effectively adsorbs microcystins – however, the exact carbon dose will vary depending on the type of carbon and the concentration of background of organic material

Conclusions

- Chlorine effectively degrades microcystins – but the rate of degradation is temperature and pH dependent
- Ozone effectively degrades microcystins
- Chlorine dioxide and UV, at the dose levels commonly employed in drinking water treatment, are not effective
- Permanganate effectively degrades dissolved microcystins – however, the typical location for permanganate addition, early in the treatment process where cyanobacterial cell concentrations are still high, sets up a potential for toxin release – vigilance is recommended

Disclaimer

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for external publication. Any opinions expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Contact information

Nicholas Dugan

dugan.nicholas@epa.gov
513-569-7239

US Environmental Protection Agency
Water Supply and Water Resources Division
26 West Martin Luther King Drive
Cincinnati, OH 45268